A

report

on

Proposed Research

for

Underwater Acoustic Wireless Sensor Networks: Energy Efficient Network.

under the

guidance of

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1. INTRODUCTION

Underwater Acoustic Sensor Networks are group of sensors and vehicles deployed underwater and networked via acoustic links, performing collaborative tasks.

Equipments:

i. Autonomous Underwater Vehicles (AUVs).
ii. Underwater sensors (UW-ASN).

In last several years, underwater sensor network (UWSN) has found an increasing use in a wide range of applications, such as coastal surveillance systems, environmental research, autonomous underwater vehicle (AUV) operation, to name a few [1]–[4]. By deploying a distributed and scalable sensor network in a 3-dimensional underwater space, each underwater sensor can monitor and detect environmental parameters and events locally. Hence, compared with remote sensing, UWSNs provide a better sensing and surveillance technology to acquire better data to understand the spatial and temporal complexities of underwater environments. Clearly, *efficient underwater communication* among units or nodes in a UWSN is one of the most fundamental and critical issues in the whole network system design.

Present underwater communication systems involve the transmission of information in the form of sound, electromagnetic (EM), or optical waves. However, each of these techniques has advantages and limitations. *Acoustic communication* is the most versatile and widely used technique in underwater environments due to the low attenuation (signal reduction) of sound in water. This is especially true in thermally stable, deep water settings. On the other hand, the use of acoustic waves in shallow water can be adversely affected by temperature gradients, surface ambient noise, and multipath propagation due to reflection and refraction. The much slower speed of acoustic propagation in water, about 1500 m/s (meters per second), compared with that of electromagnetic and optical waves, is another limiting factor for efficient communication and networking. Nevertheless, the currently favorable technology for underwater communication is upon acoustics. On the front of using *electromagnetic (EM) waves* in radio frequencies, conventional radio does not work well in an underwater environment due to the conducting nature of the medium, especially in the case of seawater. However, if EM could be working underwater, even in a short distance, its much faster propagating speed is definitely a great advantage for faster and efficient communication among nodes. *Free-space optical (FSO) waves* used as wireless communication carriers are generally limited to very short distances because the severe water absorption at the optical frequency band and strong backscatter from suspending particles. Even the clearest water has 1000-times the attenuation of clear air, and turbid water has more than 100-times the attenuation of the densest fog. Nevertheless, underwater FSO, especially in the blue-green wavelengths, offers a practical choice for high-bandwidth

communication (10-150 Mbps) over moderate ranges (10-100 meters). This communication range is much needed in harbor inspection, oil-rig maintenance, and linking submarines to land, just name a few of the demands on this front.

2. COMMUNICATION REQUIREMENTS FOR UNDERWATER SENSOR NETWORKS

The underwater sensor networks (UWSNs) targeted by this paper are underwater networks with densely deployed sensor nodes. High node density is the key characteristic of such networks. Depending on the applications, we can roughly classify the targeted dense sensor networks into two categories:

i. UWSNs for long-term non-time critical aquatic monitoring applications (such as oceanographic data collection, pollution monitoring/detection, and off-shore oil/gas field monitoring).

ii. UWSNs for short-term time-critical aquatic exploration applications (such as submarine detection, loss treasure discovery, and hurricane disaster recovery) [5]. The former category of UWSNs can be either mobile or static depending on the deployment of sensor nodes (buoyancy-controlled or fixed at sea floor), while the latter category of UWSNs are usually mobile since it is natural to imagine that the cost of deploying/recovering fixed sensor nodes is typically forbidden for short-term time-critical applications. To summarize, we will focus on three types of UWSNs:

1) Mobile UWSNs for long-term non-time critical applications (*M-LT-UWSNs* for short).
2) Static UWSNs for long-term non-time critical applications (*S-LT-UWSNs* for short).
3) Mobile UWSNs for short-term time-critical applications (*M-ST-UWSNs* for short).

Obviously, different types of UWSNs have different communication requirements. We summarize the communication requirements for all three types of UWSNs in Table 1.

TABLE 1
COMMUNICATION REQUIREMENS OF UWSNs

Requirements	M-LT-UWSNs	S-LT-UWSNs	M-ST-UWSNs
Data Rate	Various	Various	Various
Transmission Range	Short (10 m-1 km)	Short (10 m-1 km)	Short (10 m-1 km)
Deployment Depth	Shallow Water	Shallow or Deep	Shallow Water
Energy Efficiency	Major Concern	Major Concern	Minor Concern
Antenna Size (RF communication)	Small	Small	Small
Real-Time Delivery	Minor Concern	Minor Concern	Major Concern

2.1 FUNDAMENTALS OF PHYSICAL WAVES AS UNDERWATER COMMUNICATION CARRIERS

Understanding the first principles of each physical wave used in UWSN wireless communication is critically important. In this section we layout the fundamental physical properties and critical issues for each of the acoustic, EM, and optical wave propagations in underwater environments. We discuss each physical carrier's advantages and disadvantages towards efficient underwater wireless communication.

A. Acoustic Waves

Among the three types of waves, acoustic waves are used as the primary carrier for underwater wireless communication systems due to the relatively low absorption in underwater environments. We start the discussion with the physical fundamentals and the implications of using acoustic waves as the wireless communication carrier in underwater environments.

1) Physical Properties: Acoustic waves has a number of propagation characteristics that are unique from other waves, two of which are highlighted below.

Propagation velocity: The extremely slow propagation speed of sound through water is an important factor that differentiates it from electromagnetic propagation. The speed of sound in water depends on the water properties of temperature, salinity and pressure (directly related to the depth). A typical speed of sound in water near the ocean surface is about 1520 m/s, which is more than 4 times faster than the speed of sound in air, but five orders of magnitude smaller than the speed of light. The speed of sound in water increases with increasing water temperature, increasing salinity and increasing depth. Most of the changes in sound speed in the surface ocean are due to the changes in temperature. This is because the effect of salinity on sound speed is small and salinity changes in the open ocean are small. Near shore and in estuaries, where the salinity varies greatly, salinity can have a more significant effect on the speed of sound in water. As depth increases, the pressure of water has the largest effect on the speed of sound. Under most conditions the speed of sound in water is simple to understand. Sound will travel faster in warmer water and slower in colder water. Approximately, the sound speed increases 4.0 m/s for water temperature arising 1 degree centigrade. When salinity increases 1 practical salinity unit (PSU), the sound speed in water increases 1.4 m/s. As the depth of water (therefore also the pressure) increases 1 km, the sound speed increases roughly 17 m/s. It is noteworthy to point out that the above assessments are only for rough quantitative or qualitative discussions, and the variations in sound speed for a given property are not linear in general. The overall effect of sound speed in seawater is illustrated in Fig. 1. The slow propagation speed of sound impacts communication system performance and network protocol design in a number of ways, as will be discussed in later sections on engineer countermeasures and networking challenges. Absorption: During propagation, wave energy may be converted to other forms and absorbed by the medium. The absorptive energy loss is directly controlled by the material imperfection for the type of

physical wave propagating through it. For acoustic waves, this material imperfection is the inelasticity, which converts the wave energy into heat.

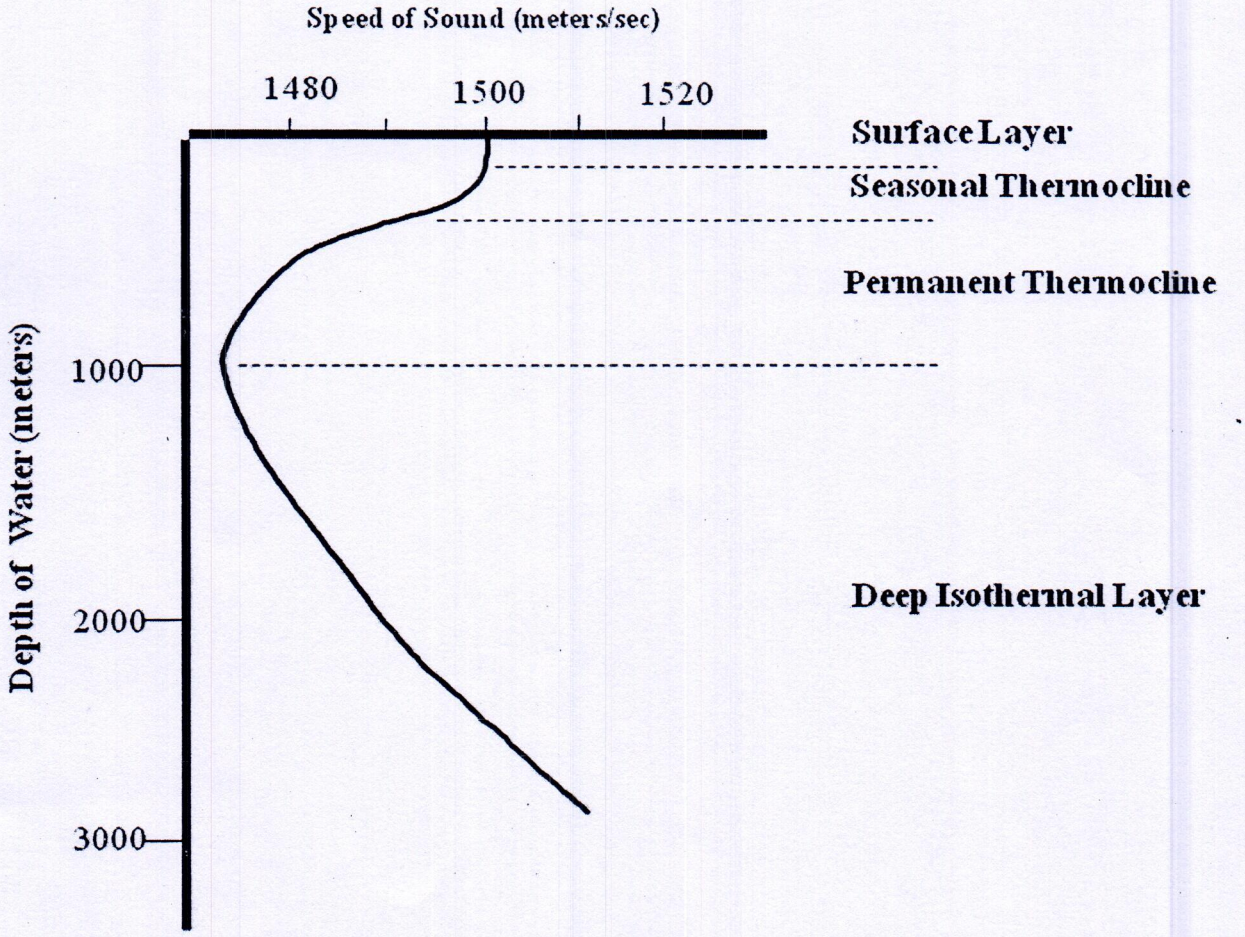


Fig. 1 The relation of speed of sound with Depth of water and temperature variations.

2) Multipath: An acoustic wave can reach a certain point through multiple paths. In a shallow water environment, where the transmission distance is larger than the water depth, wave reflections from the surface and the bottom generate multiple arrivals of the same signal. In deep water applications, surface and bottom reflections may be neglected. However, the wave refractions due to the spatially varying sound speed cause significant multipath phenomena. Assume that there are P distinct paths between the source and the receiver, and let τp denote the propagation delay for the pth path. Further, we use D to denote the *channel delay spread*, defined as the time difference between the first and the last arrivals of multipath propagation, i.e., $D = \tau_{P-1} - \tau_0$. Due to the slow speed, the channel delay spread from multipath propagation is large. For example, two physical arrivals that differ 15 meters in path length leads to an arrival time difference of 1 ms (here we assume the propagation speed of sound is 1500 m/s). Typical underwater channels have delay spread around 10 ms, but occasionally delay spread can be as

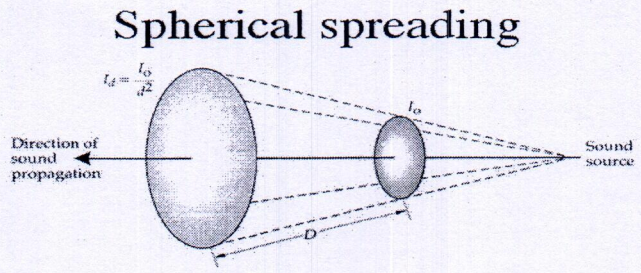
large as 50 to 100 ms [6]. Large channel delay spread introduces time dispersion of a signal, which causes severe *inter-symbol interference*. Consider a signalling scheme with bandwidth of $B = 4$ kHz. Each symbol interval is about $Ts = 0{:}25$ ms. In the presence of a channel with delay spread of 10 ms, each symbol will affect the subsequent $10{=}0{:}25 = 40$ symbols due to waveform spreading. This brings grand challenges for efficient modulation and demodulation.

3) Path Loss: We now discuss the energy loss along each propagation path [7]. For any propagation wave, there are three primary mechanisms for energy loss: (i) geometric spreading, (ii) absorptive loss, and (iii) scattering loss.

We next focus on geometric spreading and scattering loss.

Geometric spreading is the local power loss of a propagating acoustic wave due to energy conservation. When an acoustic impulse propagates away from its source with longer and longer distance, the wave front occupies larger and larger surface area. Hence, the wave energy in each unit surface (also called *energy flow*) becomes less and less. For the spherical wave generated [8] by a point source, the power loss caused by geometric spreading is proportional to the square of the distance. On the other hand, the cylindrical waves generated by a very long line source, the power loss caused by geometric spreading is proportional to the distance.

Scattering is a general physical process whereby one or more localized non-uniformities in the medium, such as particles and bubbles, force some forms of wave radiation to deviate from a straight trajectory. It also includes deviation of reflected radiation from the angle predicted by the law of reflection. This is especially relevant to underwater channels. When the wind speed increases, the surface roughens and the effect of surface scattering becomes evident [5]. Surface scattering introduces not only power loss, but also spreading in delay of each surface bounce path.



- Loss in sound intensity follows the inverse square law: pressure halves for each doubling of distance, i.e. - 6 dB for each doubling of distance

Fig. 2 Spherical Spreading

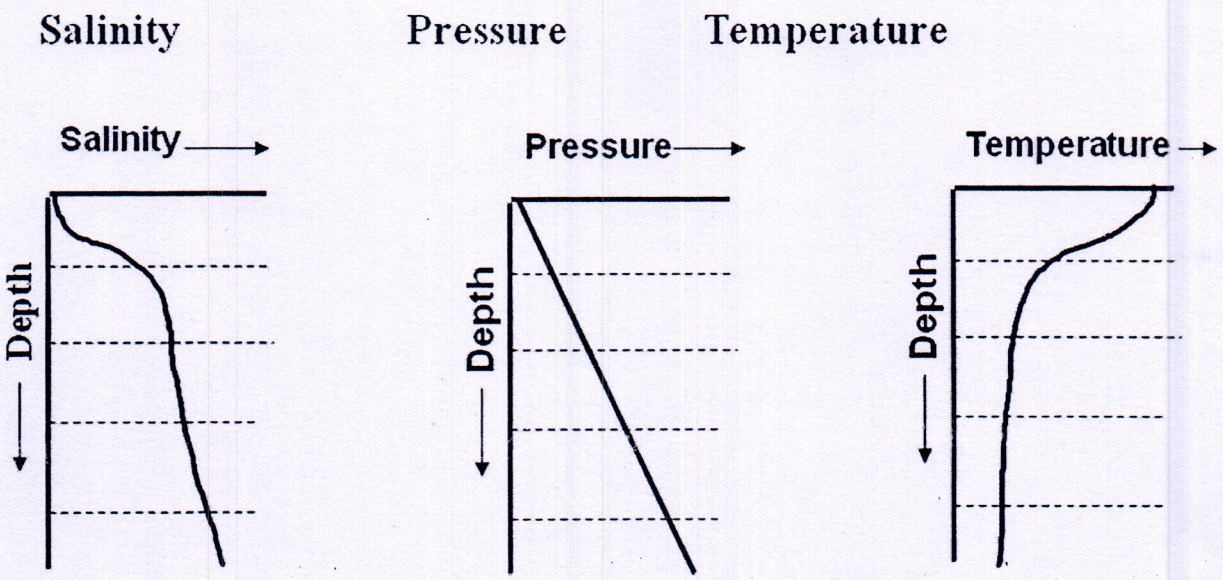


Fig. 3 The variation in velocity of sound w. r. t. Salinity, Pressure and temperature.

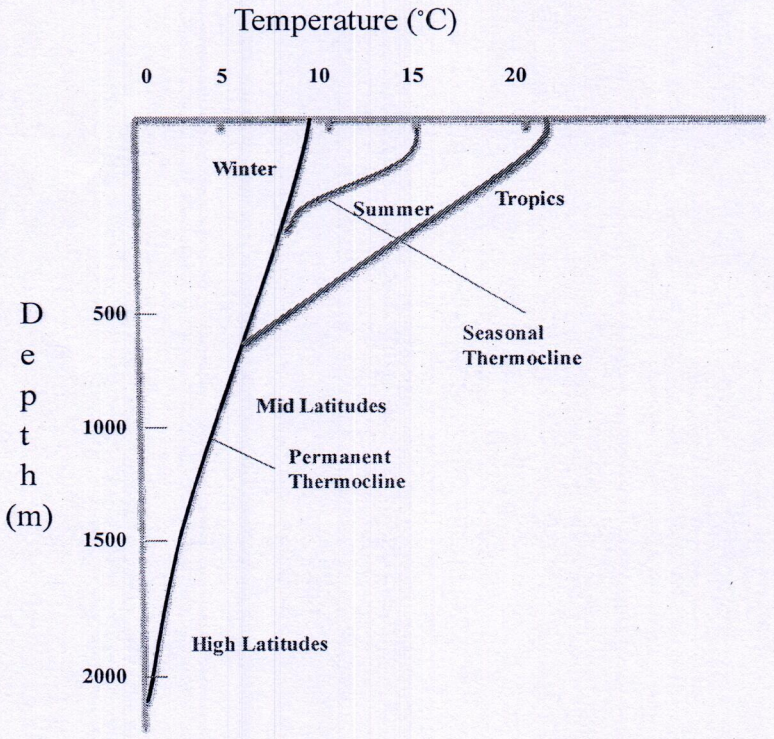


Fig. 4 The temperature variation of sea water due to Seasonal Thermoclines.

3. PROPOSED RESEARCH

The research plan proposed in this report is in infant state. The broad plan for initial proceedings is given in TABLE 2. The topic of research will become more confined and precise as research proceeds further.

TABLE 2. RESEARCH PLAN

S. No.	Research Work
1	Topology structure design for Underwater Acoustic Wireless Sensor Network.
2	An energy efficient topology structure which improves performance and lifetime of the network.
3	To develop propagation delay model for Underwater Acoustics Sensor Networks using mathematical expressions. Due to uncertain conditions and random variation in water characteristics it is difficult to model the delay propagation model.
4	To develop energy efficient network when acknowledgements are used and find out the optimal performance value.
5	The work will be based the MAC protocols of UAWSNs.
6	In the starting phase the work is based on the performance improvement using Contention-based protocols like CSMA/CD, CSMA/CA.
7	The research work on two dimensional UAWSNs topologies with moderate mobility.
8	The research work on two dimensional UAWSNs topologies with high mobility.
9	The initialization of research work on three dimensional UAWSNs topologies with moderate mobility.
10	The initialization of research work on three dimensional UAWSNs topologies with high mobility.
11	To find out different methods, techniques and protocols to improve the performance and lifetime of UAWSNs in high mobility architectures.

4. CHALLENGES

The challenges which are dominating in UAWSNs are as follows:

i. The available bandwidth in UASNs is very narrow.
ii. The radio waves are not suitable for underwater communication.
iii. The propagation delay in UAWSNs is very high due to the low velocity of sound in water.
iv. The frequent variation in topology because of aquatic animals, streams, submarines, boats and ships.
v. The underwater sensors are very prone to failure due to corrosion.
vi. High attenuation due to the absorption of sound waves.
vii. Generally, Underwater Sensor Networks architectures are 3-D structures. It is a challenge to construct it and maintain it.

5. SIMULATION RESULTS

5.1 Simulation1

Title: Performance Evaluation of GTSP Topology in WSN using Distributed Simulation Time.

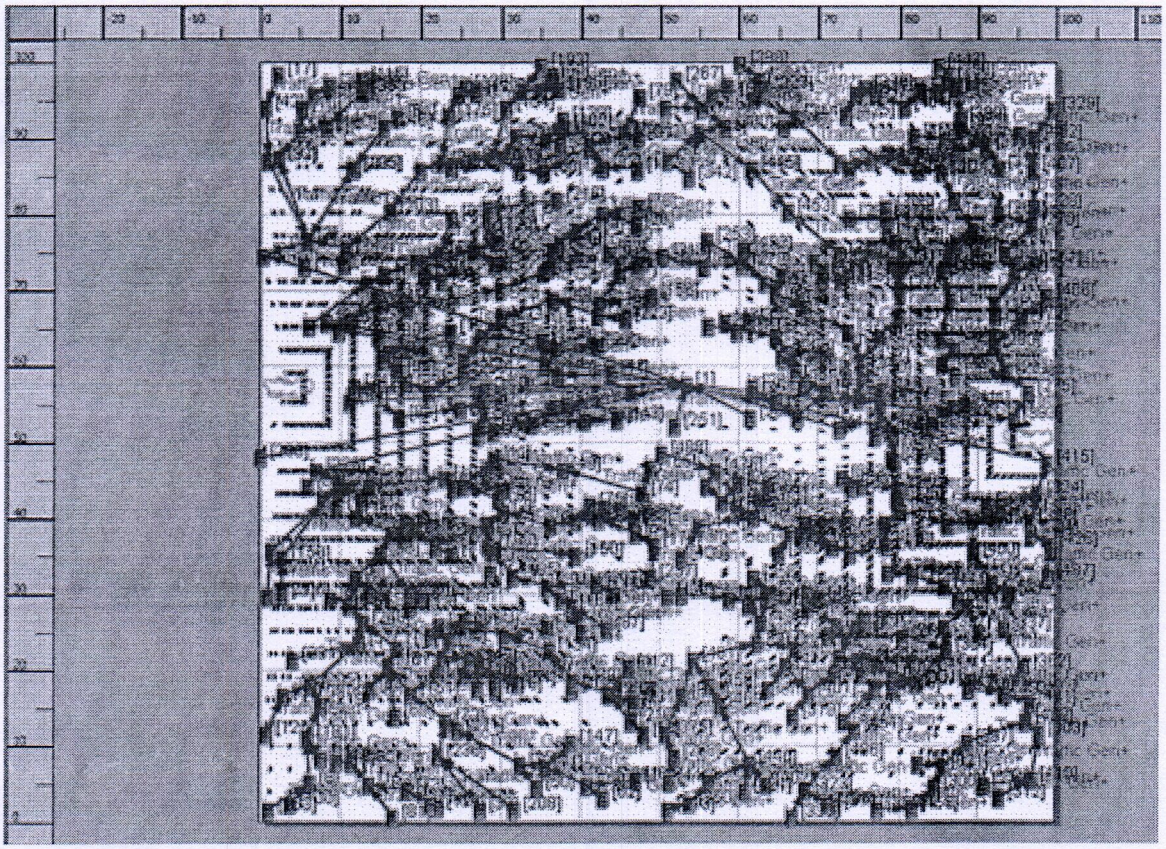


Fig. 5 Simulation Scenario

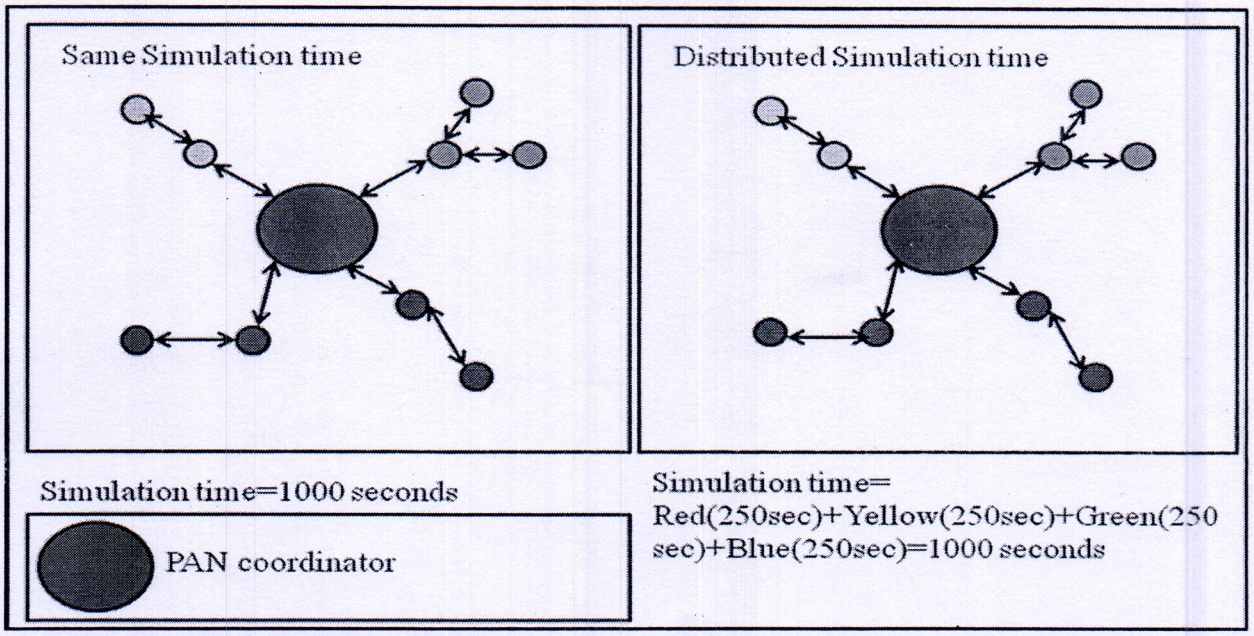


Fig. 6 Schematic of the Simulation Scenario

TABLE 3. SIMULATION RESULT

Parameters	Same Simulation Time	Distributed Simulation Time
Network Lifetime (Days)	59.3288718	136.3527281
Throughput (Bits/second)	155.81366	381.489661
End to End Delay (Seconds)	35.062507	133.58657
Jitter (Seconds)	5.8055508	31.607126
No. of Packets Dropped	934636	721146

5.2 Simulation 2

Title: Performance Comparison of Topologies for Underwater Acoustic Wireless Sensor Network

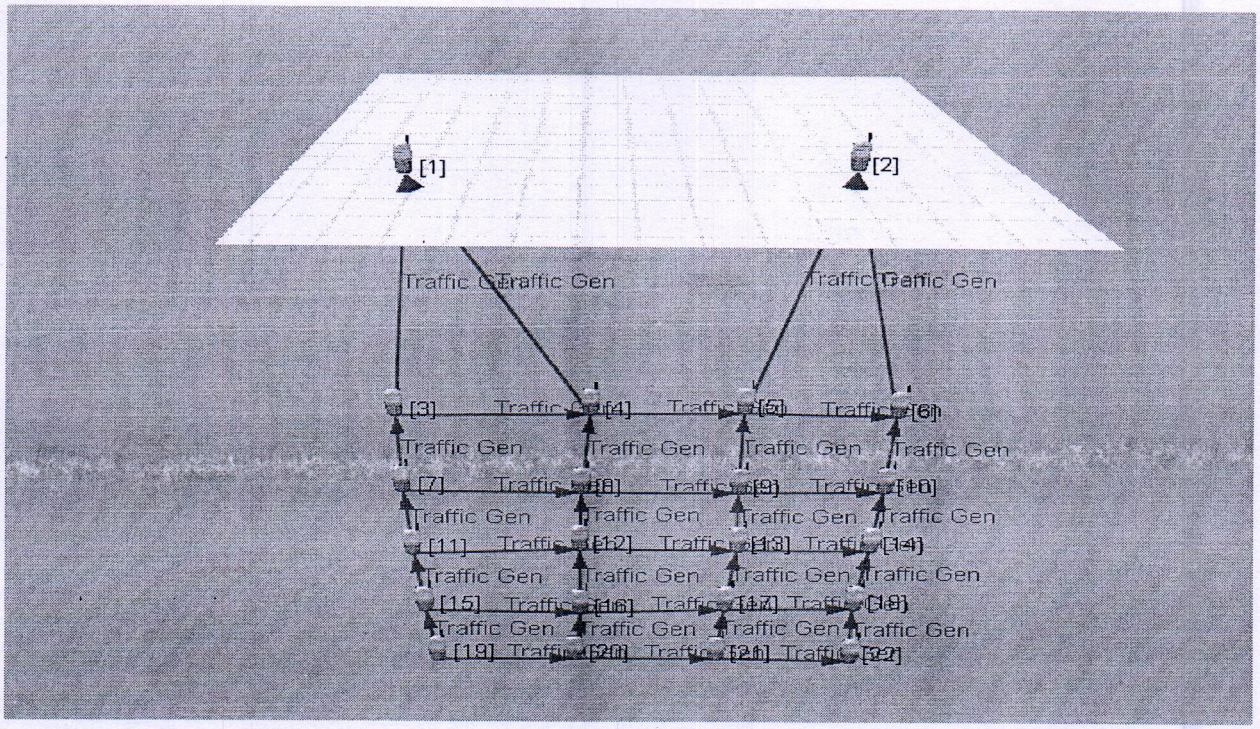


Fig. 7 Simulation Scenario for Square Topology Structure

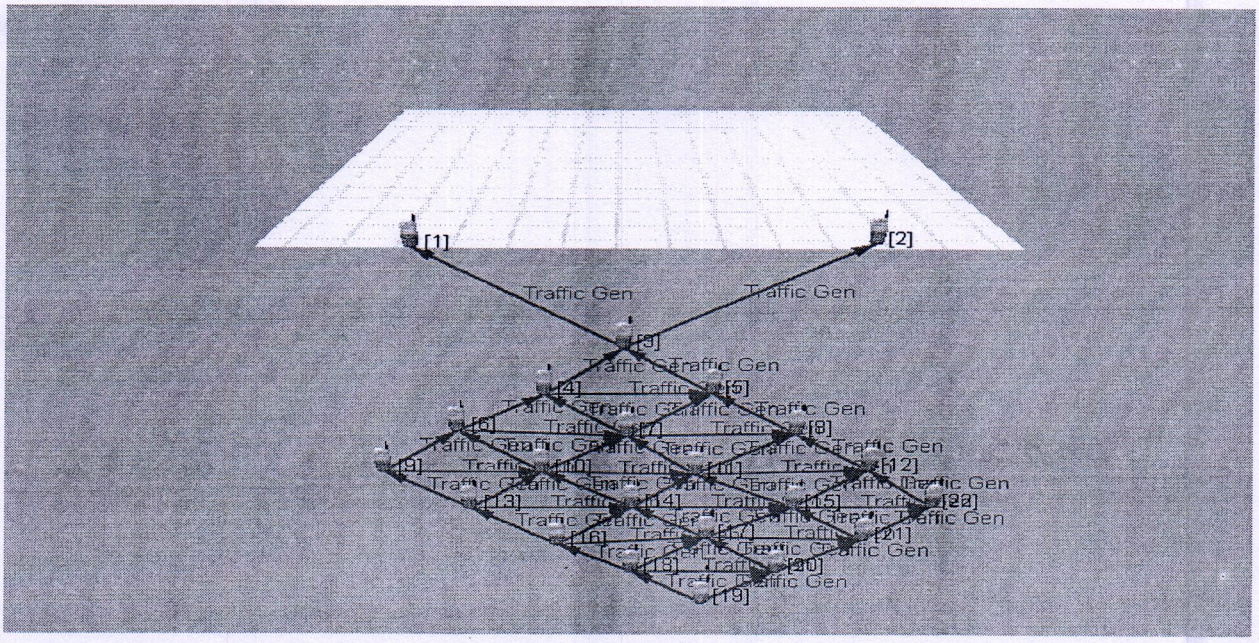


Fig. 8 Simulation Scenario for Triangular Topology Structure

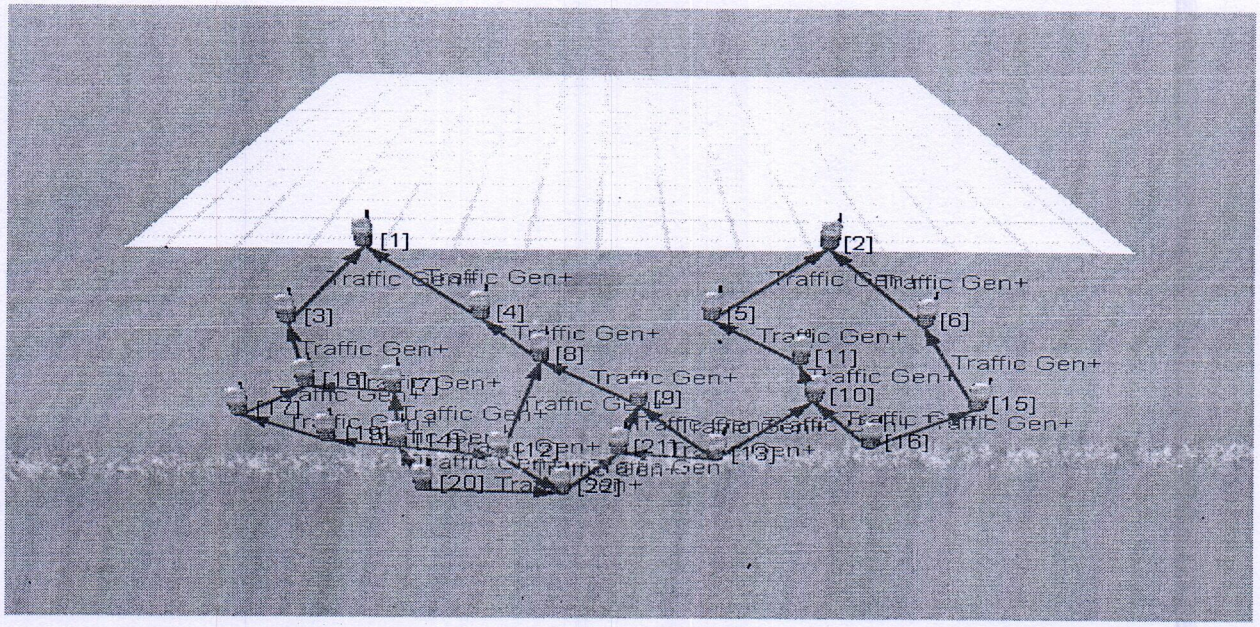


Fig. 9 Simulation Scenario for GTSP Topology Structure

TABLE 4. SIMULATION RESULT

Parameters	Square Topology Structure	Triangle Topology Structure	GTSP Topology Structure
Network Lifetime (Days)	14.6901	14.2118	15.6695
Throughput (Bits/second)	655.1839	374.8487	769.4562
End to End Delay (Seconds)	154.4656	264.7499	221.9723
No. of Packets Dropped	7389	10837	5997

6. FUTURE WORK

As our future work, we will investigate whether optimal performance metrics exists for irregular topologies and various routing schemes. Moreover, we will further steer our research from constant to varying assumptions like variable space between sensor nodes and variable propagation delay [9]. The analysis and comparison of UASNs using contention based MAC protocols (CSMA/CA, CSMA/CD etc.) and contention less MAC protocols like (TDMA, polling etc.). The implementation of various topologies and protocols in mobility based two dimensional and three dimensional architectures are major fields of research.

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